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Science Literacy and the Application of Scientific Knowledge

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Introduction

In formulating the objectives and goals of science education, considerations of social needs have received increasingly more attention over the past few decades. Within the socially relevant body of knowledge, a key role is assigned to skills and competencies that provide an awareness of natural sciences, enable students to apply their knowledge in everyday life, equip them for independent learning, for the acquisition of information and for decision-making, and help them become responsible members of their society. A major line of research in natural science education is concerned with social issues of education, the nature of relevant knowledge, the interpretation of science literacy, the comprehensive analysis of the various models (e.g., Aikenhead, 2007; Bybee, 1997b; Jenkins, 1994; Laugksch, 2000; Pella, O'Hearn & Gale, 1966; Roberts, 2007) and the planning, analysis and evaluation of educational programs and teaching and learning environments focusing on scientific literacy.

The greatest challenge of science education is to keep up with the development of science and technology and with the changes in the modern social and economic environment. It has become clear by now that a discipline-centred approach to education mirroring the structure and logic of specialised branches of science is in itself incapable of the efficient teaching of the ever newer results of science while satisfying the changing needs of society. Empirical research has shown that the successful application of the scientific knowledge acquired through traditional teaching methods at school is largely limited to the original environment of acquisition, therefore, it is difficult to transfer this knowledge to contexts outside of the school (Csapó, 1999). The results of research on the organisation, acquisition and use of knowledge indicate that the development of reasoning and efficient learning skills plays a major role in the development of applicable knowledge. The data gathered during the past decades show that the ability to apply knowledge to new situations and in a variety of contexts is improved by teaching methods encouraging active knowledge acquisition and independent learning. Efficient education also takes the social embeddedness of science, the scenes and modes of knowledge acquisition outside of school into account, and attempts to narrow the gap between formal and natural learning. While the idea that education should meet socio-economic needs receives the greatest emphasis in the theoretical framework of the Organisation for Economic Co-operation and Development, Program for International Student Assessment (OECD PISA) programs several countries have also made efforts to develop literacy standards conforming to national characteristics and cultural traditions, to establish practices encouraging science education, and to measure scientific knowledge on a regular basis. The first part of this chapter discusses the diverse approaches to scientific literacy, outlines the models representing the principal trends in national standards and international studies, and presents some specific concepts of literacy. The second half of the chapter reviews the structure of scientific literacy and of the knowledge expected to be acquired and intended to be measured, discusses the curricular and assessment requirements, and analyses the issues of knowledge application.

Different Approaches to Science Literacy

The present-day interpretation of the objectives of science education can be traced back to Conant (1952), a Professor of Chemistry, a former president of Harvard University. In the early fifties, he was the first to note that the knowledge of the facts of science and technology is relatively low-level knowledge in itself, and he emphasized the importance of the comprehensive understanding of science (Bybee, 1997b). The term *scientific literacy* encompassing the basic principles and objectives of science education was coined by Hurd (1958) and McCurdy (1958). *Scientific literacy* as a concept standing for the goals of 'school science' became a common term in the Anglo-American literature debating curriculum developments in the second half of the 20th century. The modern interpretation of the concept relating scientific knowledge to practice and to fields other than science did not, however, emerges until much later (Roberts, 2007). In the 1980s, the term *scientific literacy* was replaced by the phrase *science literacy* in the projects of the *Science-Technology-Society* (STS) and then in the theoretical framework of the PISA program of the OECD (Roberts, 2007). Although the two phrases (*scientific/ science literacy*)[1] are translated with the same expression in the Hungarian literature, there is a difference between them in terms of both content and emphasis. The term *science literacy* is usually used by authors in a wider sense. Within the theoretical framework of *Project 2061* (American Association for the Advancement of Science [AAAS]) it refers to the basic principles of literacy closely related to the natural sciences (AAAS, 1983; 1989; 1990; Roberts, 2007). According to Maienschein's (1998) analysis, the phrase *science literacy* can be associated with approaches focusing on the acquisition of science and technology-related knowledge, whereas the phrase *scientific literacy* is used primarily in definitions emphasising a scientific approach to knowledge acquisition and creative thinking about the physical world.

Today several conceptions of literacy exist side by side differing in detail and complexity (Jenkins, 1994; Roberts, 1983). A number of researchers have attempted to review and systematise the many kinds of

1 A form used more rarely, but with the same meaning and function is *scientific culture* (please refer e.g., to Solomon, 1998), and in French-speaking regions (e.g., Canada) '*la culture scientifique*' (Durant, 1993).

interpretations. These studies categorise the various approaches to literacy according to different guiding principles and criteria. Laugksch (2000) observes, for instance, that the interests and objectives of teachers and other professionals involved in science education are a decisive factor in their definition of concepts and tasks and in their placement of emphasis. Primary and secondary school teachers thus aim to specify in the curriculum the skills, attitudes and values related to their objectives, and to interconnect educationally relevant scientific results, teaching methods and assessment. Sociologists and other researchers in social sciences with an interest in natural sciences, who mainly work with adults, emphasise the power of science and technology, and the importance of scientific knowledge needed in everyday life. Those involved in natural science education outside of school (e.g., educators working in botanical gardens, zoological gardens or museums), writers and journalists focus on the development of the literacy of a wide range of age groups (children, teenagers, adults, the elderly), on comprehensibility and on the dissemination of applicable knowledge.

In his overview of the different definitions of scientific literacy, Roberts (2007) identifies the following approaches: (1) a historical approach, which is common among qualified teachers, (2) an approach built on the assumed needs of students, focusing on types and levels of literacy, (3) an approach concentrating on the word literacy, (4) an approach focusing on the natural sciences and natural scientists, (5) and an approach centred on situations or contexts of everyday life related to science. The author assigns literacy conceptions to two categories clearly distinguishable in terms of their view of the fields of natural science and the relationship between them. One of these is 'Vision I, rooted in the products and processes of science,' which is associated with the traditional school teaching of science, – see e.g., Shamos's (1995) model. The models adopting 'Vision II' emphasise the understanding of situations and contexts which are likely to occur in the everyday lives of target groups and which contain science components or are in some way related to the principles and laws of science – one example is the conceptual and procedural literacy level described by Bybee (1997a). Roberts (2007) points out that for 'Vision I' a situation is just a symbolic component of literacy, while in 'Vision II' the different disciplines of science do not receive sufficient emphasis.

Aikenhead (2007) proposes a third category to supplement 'Visions I and II,' which are both based on the conventional notion of science and on its disciplinary versus interdisciplinary conception. Aikenhead terms the complex, plural definitions of the third category combining natural sciences with other disciplines (with social sciences, such as sociology) 'Vision III' after *Roberts*. One example is the view on literacy embraced by the STS projects (Aikenhead, 1994; 2000; 2003b; B. Németh, 2008; Fensham, 1985; 1988; 1992). The conceptions of literacy used in practice are individual manifestations and various combinations of Roberts' 'Visions'(Aikenhead, 2007; Roberts, 2007).

Holbrook and Rannikmae (2009) distinguish two opposing poles of literacy models: those focusing on the *knowledge of science* and those emphasising the usefulness of *science literacy*, between which Gräber's (2000) model creates a bridge.

The models varying in their approaches and in their formulations – as discussed in the comprehensive analytical studies cited above (Aikenhead, 2007; Gräber, 2000; Holbrook & Rannikmae, 2009; Laugksch, 2000; Roberts, 2007) – characterise scientific literacy from differing perspectives and along varying dimensions. A feature common to these approaches is, however, that almost all of them describe the competencies a scientifically literate individual possesses, what this individual knows and is able to do. Some literacy concepts list the components regarded to be important, and specify the various forms of literacy corresponding to these components (*descriptive literacy models*). Other approaches distinguish different, hierarchically organised levels emerging with the development of reasoning (*developmental models*). A third group comprises theories characterising scientific literacy through the concept of competency and competency models (*competency based definitions*). In what follows, the diversity of approaches to literacy will be illustrated through a discussion of a widely cited representative of each of the three categories, including the literacy interpretations of the two most significant international assessment studies, the IEA TIMSS[2] and the OECD PISA programs.

2 IEA: International Association for the Evaluation of Education Achievement
The TIMSS acronym in itself refers to the four joint projects in mathematical and natural science organised between 1995 and 2007 (www.timss.bc.edu). Reports: in 1995 TIMSS (Third International Mathematics and Science Study); in 1999 TIMSS-R (Third International Mathematics and Science Study Repeat); in 2003 TIMSS (Trend International Mathematics and Science Study); in 2007 TIMSS (Trends in International Mathematics and Science Study).

Descriptive Approaches to Literacy

Forty years after the appearance of the term *scientific literacy*, *Hurd* (1998) interprets the concept in terms of the role it plays in culture. He lists seven patterns of behaviour required for the interpretation of the relationship between nature and technology. According to that, an individual competent in natural sciences …

(1) understands the nature of knowledge;
(2) applies appropriate science concepts, principles, laws and theories in interacting with his universe;
(3) uses the processes of science in problem solving, making decisions, and furthering his own understanding of the universe;
(4) interacts with the values that underline science;
(5) understands and appreciates the joint enterprise of science, and the interrelationship of these with each other and with other aspects of society;
(6) extends science education throughout his or her life;
(7) develops numerous manipulative skills associated with science and technology.

An approach to literacy similar to Hurd's is reflected in Klopfer's (1991) model, which contends that scientific literacy providing important general knowledge for everyone includes the knowledge of essential scientific facts, concepts, principles and theories, the application of this knowledge in everyday situations, the ability to learn and use scientific research processes, a thorough understanding of the nature of interactions between science, technology and society, and a scientific curiosity and attitude.

Hackling and Prain's (2008) model, which provides the theoretical background for the Australian *National Assessment Program - Science Literacy (NAP-SL),* constructs a picture of scientific literacy from elements reminiscent of Klopfer's model. Hackling and Prain (2008, p. 7) see scientific literacy as knowledge constructed from knowledge of the nature of science, from a thorough conceptual understanding allowing applications in everyday life, from scientific competencies, and from a positive attitude towards and interest in science.

Shen (1975) defines science literacy as knowledge related to the natural, medical and engineering sciences coming from different sources, including learning in the school and outside of school. The author identifies three types of science literacy based on the organisation of dominant components: (1) practical science literacy, through which the problems of everyday life can be solved, (2) civic science literacy, which ensures social integration through an understanding of science and issues connected with it, and (3) cultural science literacy, which involves scientific curiosity.

The Scientific Literacy Framework of the IEA-TIMSS Surveys

The IEA TIMSS international comparative surveys, which have some of the greatest impact on education system development, are designed to gather data for education policy and school subject development, and to monitor the attainment of curricular goals and evaluate the quality of the attained curriculum (Olsen, 2004). The theoretical basis of the 'descriptive rationale-based' TIMSS projects (Olsen, Lie, & Turmo, 2001) is provided by the so-called international curriculum panel created through an analysis of participating countries' intended curricula indirectly reflecting social expectations (Mullis et al., 2005). The nature of the knowledge/literacy measured by the TIMSS surveys is described in published background materials detailing the theoretical framework of the surveys. The surveys focus on knowledge associated with traditionally defined fields of science. The theoretical framework of the TIMSS projects embraces an approach involving expert knowledge, i.e., it gives rise to models based partly on true scientific literacy of the type described by Shamos (1995), and partly on learnt knowledge in Laugksch's (2000) sense and on the concepts identified by Roberts (2007) as 'Vision I'. The two most recent – 2003 and 2007 – cycles of the TIMSS surveys also included some elements of Bybee's (1997a) procedural view and of Roberts' 'Vision II'.

In the surveys of the IEA, science literacy is defined explicitly only in the theoretical framework of the IEA TIMSS study of 1995 designed to assess the performance of final year secondary school students (Population III). In that work, science literacy is defined as knowledge of science sufficient for the solving of everyday problems. The document identifies three components of knowledge useful in everyday situations: (1) familiarity with the basic principles of the various disciplines,[3] (2) reasoning in mathematical, natural and engineering sciences, and (3) familiarity with the social effects of science and technology, and with the social utility of mathematics, science and technology (Orpwood & Garden, 1998, pp. 10–11). However, the latter two components – Reasoning and Social Utility (RSU) – had limited contribution to the study as they were represented by only 12 items (15.8 per cent of the total number of items) (Adams & Gonzalez, 1996), and these items were completed by secondary school students in only a few countries (Orpwood, 2001).

Development Models

The Shamos[4] (1995) and Bybee[5] (1997a) models regarded as corner points in the relevant literature (Aikenhead, 2007; Gräber, 2000; Holbrook & Rannikmae, 2009; Laugksch, 2000; Roberts, 2007) view scientific literacy as a knowledge structure emerging in harmony with the evolution of reasoning. In both models, the organisation of knowledge is realised in steps building upon one another. Each individual level is characterised by a system of given complexity allowing the completion of tasks of a corresponding degree of difficulty (Bybee, 1997a; Shamos, 1995).

According to Shamos (1995), the most developed and highest-level true scientific literacy essentially consists of knowledge of the major conceptual schemes and the recognition of values and the importance of analytic and deductive reasoning and the significance of scientific problems (Figure 2.1). The emergence of such broad scientific knowledge is contingent on the availability of background knowledge including the elements of scientific communication, cultural scientific literacy as well as functional scientific literacy built upon it, which allows the use of scientific language and fluent oral and written discourses in different situations. Regarding the teaching of science, Shamos (1995) emphasises the importance of logical reasoning, quantitative analysis, meaningful questioning and reliance upon sound evidence as opposed to imparting knowledge content (Shamos, 1995).

3 Earth Science, Human Biology, Other Life Sciences, Energy and Other Physical Sciences
4 Shamos (1995) model: ‘Vision I’ (Roberts, 2007); meta-competence (Gräber, 2000
5 Bybee (1997a) model: ‘Vision II’ (Roberts, 2007); material competence (Gräber, 2000)

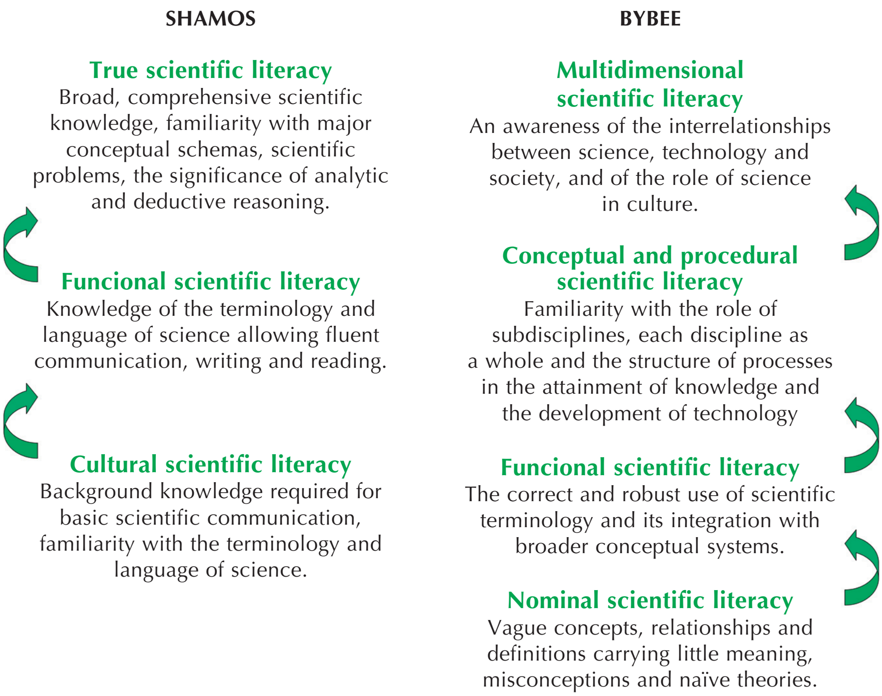


Figure 2.1
Shamos (1995) and Bybee's (1997a) hierarchical models of development

Bybee (1997a) links technical and scientific literacy to the development of conceptual reasoning, and describes literacy as a hierarchically constructed system resulting in an increasingly thorough understanding of the phenomena of science and technology and the interactions between them. According to the model (Figure 2.1), the knowledge of a student is first characterised by concepts and relationships having little meaning, misconceptions and naive theories. This is termed *nominal scientific literacy*, which, with the development of broader conceptual systems, grows into *functional scientific literacy*, i.e., a set of scientific tools that can be used robustly in certain limited contexts. The third level of development, *procedural scientific literacy* enables the learner to understand the structure of the individual fields and processes of science and recognise its role in knowledge acquisition and in the development of technology. Finally, the main conceptual systems of science will be arranged in multidimensional structures giving rise to *multidimensional scientific literacy*, with the help of which the different fields of science, the relationships between science, technology and society, as well as the role played by science in culture and society becomes interpretable. According to Bybee (1997a), this highest organisational level is primarily required by people working in areas related to science (B. Németh, 2008; Bybee, 1997a).

An intention to develop a broad scientific literacy – similar to Bybee's procedural literacy concept – needed for success in everyday life can be observed in the US National Science Education Standards (NSES) published in 1996 in the United States. According to the definition of the National Research Council (NRC), scientific literacy useful for everyone consists of the knowledge and understanding of scientific concepts and processes that help in making individual decisions (NRC, 1996). Scientific literacy empowers people to understand articles published in the popular press (not science journals) discussing science topics and reporting scientific achievements, and to participate in public discourses concerning the validity of the conclusions drawn. Scientific literacy encompasses the comprehension of scientific statements justifying national and local decisions as well as the ability to take a stance based on scientific and technical information. An individual educated in science is capable of describing and explaining natural phenomena, of judging the value of scientific information on the basis of its source and the way it was produced, and of organising, evaluating and applying evidence-based arguments (B. Németh, 2010; NRC, 1996, p. 22).

The revised assessment framework published in 2005 specifies familiarity with the history of science, the scientific forms of thinking, the social and individual perspectives of science, and the characteristics of scientific initiatives as parts of scientific literacy. It highlights three elements for the purposes of assessment: (1) scientific knowledge, (2) scientific reasoning, and (3) the understanding and application of the nature of scientific discovery (Wilson & Bertenthal, 2005, pp. 38–39).

"The goals for school science in the NSES are to educate students that are able to

(i) use scientific principles and processes appropriately in making personal decisions

(ii) experience the richness and excitement of knowing about and understanding the natural word
(iii) increase their economic productivity, and
(iv) engage intelligently in public discourse and debate about matters of scientific and technological concern." (Lederman & Lederman 2007, p. 350)

The influence of the Bybee model can be detected in the Scientific and Technological Literacy (STL) project concerning classroom activities of the OECD PISA program and of UNESCO. UNESCO distinguishes

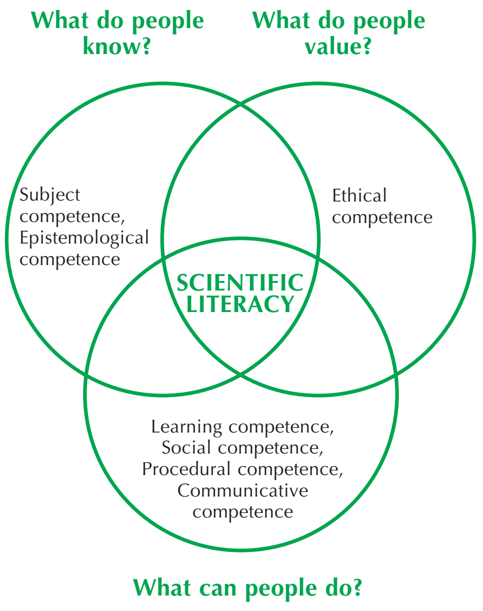
"(1) *Nominal STL literacy*: students identify terms and concepts as being scientific in nature, but they have misconceptions and only provide naive explanations of scientific concepts.
(2) F*unctional STL literacy*: students can describe a concept but with a limited understanding of it.
(3) *Structural STL literacy*: students are interested in the study of a scientific concept and construct appropriate meaning of the concept from experiences.
(4) *Multi-dimensional STL literacy*: Students understand the place of science among other disciplines, know the history and nature of science, and understand the interactions between science and society. The multi-dimensional level of literacy cultivates and reinforces life-long learning in which individuals develop and retain the need to know, and have acquired the skills to ask and answer appropriate questions." (UNESCO, 2001, p. 21)

Competence-Based Approaches

The third large group of approaches to literacy emphasises the complexity of scientific literacy, and the complex nature of knowledge required for problem-solving. It uses competency models[6] to characterise basic expectations. One of the most-cited competence-based approaches is Gräber's model (2000), with an underlying assumption that scientific

6 At this point a terminological clarification is required regarding the usage of competence and competency. Examining the usage of these two concepts in the cited literature suggests that there is a slight difference between the connotations associated with each term. Therefore, the authors use these words in accordance with how they occur in the primary sources. In other contexts, in the plural, only the term competencies is used in this chapter.

literacy that prepares people for the challenges of our complex world is composed of problem solving competencies. In the model, scientific literacy is the cross-section of the competencies related to three problem areas – 'What do people know?' 'What do people value?', and 'What can people do?' – a complex system of subject-related, epistemological, ethical, learning, social, procedural and communication competencies (Figure 2.2).



– *Subject-competence.* includes declarative and conceptual knowledge: a continuum of science knowledge and understanding throughout the various domains of science. When combined, depth and breadth provide an individual profile of science knowledge and understanding.
– *Epistemological competence* includes insight into (the general idea of) the systematic approach of science as one way of seeing the world, as compared with technology, the fine arts, religion, etc.
– *Ethical competence* includes knowledge of norms, an understanding of the relativity of norms in time and location, and the ability to reflect norms and develop value hierarchies.
– *Learning competence* includes the ability to use different learning strategies and ways of constructing scientific knowledge.
– *Social competence* includes the ability to cooperate in teams in order to collect, produce, process or interpret. in short, to make use of scientific information.
– *Procedural competence* includes abilities to observe, to experiment, to evaluate; an ability to make and interpret graphic representations, to use statistical and mathematical skills, to investigate literature. It also includes the ability to use thought models, to analyze critically, to generate and test hypotheses.
– *Communicative competence* includes competence in using and understanding scientific language, reporting, reading and arguing scientific information.

Figure 2.2
The model of scientific literacy (Gräber, 2000, p. 106)

The concept of competency is used not only for individual literacy models, but also for systematising different approaches, and for describing the different developmental levels of literacy. In the analysis of Gräber (2000), the definitions of scientific literacy form a continuum between subject-competence at one end and meta-competence at the other; one of the terminal points is represented with the model of Shamos (1995) focusing on methods and procedures, and the other end is occupied by the theory of Bybee (1997a) emphasising everyday situations and cross-curriculum competences.

Klieme et al. (2003) use the competence theory of Weinert (2001)[7] to define scientific competencies and classify literacy approaches. Pairing the goals of education with real, specific problems, the authors identify four different categories: normative, structural, developmental and empirical literacy models. In terms of this classification, the theoretical framework of IEA-TIMSS is an empirical model, and the procedural approach of Bybee (1997a) is a normative model (Schecker & Parchmann, 2006, p. 49 and p. 52). Using a normative model representing the principles of science education and its traditional fields, the German National Educational Standards (Nationale Bildungsstardards [NBS]) define curriculum requirements with respect to the three disciplines (biology, physics and chemistry) to be met on completion of lower secondary school (Grade 10) (Schecker & Parchmann, 2007).

The curriculum standards of Taiwan also rely on the concept of competence in their specification of the set of requirements expected from students of different ages. The Taiwan curriculum standards use competence indicators to characterise students' level of knowledge/literacy attained by the end of grades 2, 4, 6 9: (1) process skills, (2) cognition of science and technology, (3) nature of science, (4) development of technology, (5) scientific attitudes, (6) habits of thinking, (7) applications of science, (8) design and production (B. Németh, 2010; Chiu, 2007).

The OECD PISA Definition of Science Literacy

One of the best-known and most effective competence-based literacy models was developed by the OECD PISA program. In contrast with the IEA TIMSS studies, the starting point of PISA approach is not the educational material specified by the curriculum and taught at schools but a concept of scientific literacy needed for success in everyday life as defined by a Functional Expert Group. Their interpretation of the concept is a special combination of Roberts' 'Visions I, II, and III' (Tiberghein,

7 *Weinert* is the founder of the conceptual system of OECD-PISA, and one of the developers of key competencies within the OECD-DeSeCo project (Weinert, 1999; 2001).

2007), with certain elements being similar to the procedural literacy level of Bybee (1997a). The model describes essential knowledge and competencies that meet economic and social expectations and are necessary for entering the labour market (Olsen, Lie, & Turmo, 2001). According to this definition, scientific literacy is "…the capacity to use scientific knowledge, to identify questions (investigate), and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity". (OECD, 1999, p. 60)

In the 2006 cycle of the OECD PISA literacy assessment, where scientific literacy was in special focus, a questionnaire aiming at measuring students' scientific and technological attitudes was also included. It was designed to assess an interest in science, support for scientific enquiry, and motivation to act responsibly towards nature and research on the natural environment (B. Németh, 2008; B. Németh, Korom, & Nagy, 2012; OECD, 2006, pp. 35–36).

According to the definition of the Science Expert Group, scientific literacy involves the followings …

"– Scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, to draw evidence-based conclusions about science-related issues.
– Understanding of the characteristic features of science as a form of human knowledge and enquiry.
– Awareness of how science and technology shape our material, intellectual, and cultural environments.
– Willingness to engage in science-related issues, and with the ideas of science as a reflective citizen". (OECD, 2006, p. 23)

Comprehensive literature reviews on the approaches to literacy have shown that the definitions of scientific literacy in the official documents of education systems and in the theoretical frameworks of assessment programmes vary greatly in terms of the relationships between the different fields of natural science and the relationships between natural science and other domains (such as social sciences) (Aikenhead, 2007; Roberts, 2007). Documents (theoretical frameworks and standards) created for specific educational, pedagogical or evaluation purposes rely on literacy models either explicitly (as in the Australian and German standards) or implicitly (as in the US standards, the theoretical framework for IEA surveys). Theoretical studies define literacy in terms of the characteristics of individuals competent in science, through the specification of the range of expected patterns of behaviour and the parameters defining these patterns (along content, cognitive and contextual dimensions), and through affective characteristics (e.g., emotional attitude).

Assessment of Science Literacy

One element shared by the slightly confusing variety of views on scientific literacy is that scientific literacy is defined as operational knowledge deployable in a range of situations that enables an individual to solve real-world problems. The successful completion of tasks presupposes an ability to decide what to do in any given situation and an ability to perform the required action. It is well known that problem-solving is facilitated by the familiarity of an environment (situation). This is because during the learning process the circumstances of the problem are registered together with the solution and the result that the recall of the knowledge required for problem solving is affected by the degree of similarity between the learning and the target situations (Tulving, 1979; Wisemann & Tulving, 1976). The knowledge/literacy to be taught and/or measured is therefore characterised by the knowledge and skills, abilities or competencies required for the desired action and by the circumstances of the situation or action, the details of its content, cognitive aspect and context.

One of the fundamental challenges facing institutional education is to be able to teach knowledge that can be applied to new problems and in situations differing from the one in which learning took place. Scientific and technical knowledge can be characterised by the answers given to questions such as ‘What?’, ‘How?’ and ‘Where, under what circumstances to know?’ (Bybee, 1997a). The operationalisation of educational goals and student performance are usually realised by recording the object of learning and knowledge (content, information/What to know?) and the cognitive mechanisms (How to know?) (e.g., in the IEA TIMSS surveys). There are relatively few three-dimensional taxonomies incorporating transfer or context (one example is the OECD PISA program/OECD, 2000; 2006).

The Assessment of Content

Two solutions are known in the literature to the problem of characterising the object (content) of an activity. In theoretical studies supporting the operationalisation of the knowledge that is to be assessed the various categories are defined in terms of types of knowledge. Zoltán Báthory (2000), for instance, distinguishes facts, concepts and correlations, while Anderson and Krathwohl (2001) and Anderson (2005, p. 10) distinguish facts, concepts and the elements of procedural and meta-cognitive knowledge.

The curriculum and assessment standards and evaluation frameworks embracing a wide range of contents categorise knowledge according to general criteria as dictated by a given definition of literacy, and in terms of the disciplines of science and their integrated thematic units. The resulting broad categories are then broken down to different levels of subtopics detailing specific knowledge content. For example, in the handbook on evaluation edited by Bloom et al. and published in 1971, Kloppfer uses content categories such as *The structure and functions of the cell*, *Chemical changes*, *Electrochemistry*, *Sound*, *Dynamics*, *Solar system*, *Oceanography*, and *The characteristics and structure of sciences* (Kloppfer, 1971, pp. 561–641).

In the United States, the organising principles of the US National Science Education Standards (NSES) are centred around the topics of *History and nature of science*, *Personal and social perspectives of science and technology, Life and physical sciences*, and *Earth and space* (Ellis, 2003, p. 39). The NSES identifies eight different categories of content – Inquiry, Physical Science, Biological Science, Earth and Space, Unifying Concepts and Processes, Science and Technology, Science in Social and Personal Perspectives and History and Nature of Science (NRC, 1996).

In the Australian National Assessment Program, scientific literacy covers four content areas based on national and regional curricula: (1) *Earth and beyond*, (2) *Energy and change*, (3) *Life and living*, and (4) *Natural and processed materials* (MCEETYA, 2006, p. 83).

In Taiwan, the system of knowledge content to be assessed covers five areas: (1) *Composition and properties of nature*, (2) *Effect of nature*, (3) *Evolution and continuity*, (4) *Life and environment*, and (5) *Sustainable development*. The subdivision of the five top-level categories creates a comprehensive and clearly organised system. For example, the subsection *Change and equilibrium* within the main subject of *Effect of nature* contains topics such as Movement and force, Chemical reactions and Chemical equilibrium (Chiu, 2007, p. 311).

The German Educational Standards (NBS) specify the educational goals related to the three traditional science disciplines and detail the content dimension under the heading of 'basic concepts'. The basic concepts are the classic questions of the fields of biology, physics and chemistry. The knowledge prescribed by the physics standards, for instance, relates to the topics of matter, energy, interaction and system (Schecker & Parchmann, 2007).

The content dimension of the science surveys of the IEA also relies on a division into separate science disciplines. The thematic units of every data collection conducted so far have covered Biology/Life science, Earth science and the two physical sciences, Chemistry and Physics. The categories representing the traditional fields of science were supplemented by the category *Environmental issues and the nature of science* in the 1995 cycle of TIMSS, by the categories of *Environmental and resource issues* and *Scientific inquiry and the nature of science* in the 1999 assessment, and by the topic of *Environmental sciences* in 2003. There has been little change in the list of the main and sub-units of the content dimension or in their relative proportions. Although the two most recent studies placed approximately equal emphasis on the various fields of science, an overall bias can be observed in favour of Biology (or life science) and Physics (B. Németh, 2008; Beaton et al., 1996; Keeves, 1992a, p. 64; Martin et al., 2000; Mullis et al., 2001, pp. 37–70; 2005, pp. 41–77; 2009, p. 50).

The OECD PISA programs strive to select knowledge content test items that are relevant, useful in real-life situations, represent foundational scientific knowledge and are important in the labour market (OECD, 1999, p. 63; 2006, pp. 32–33). Although in the OECD PISA surveys, neither the content prescribed by the curricula, nor the content that has been taught at schools is relevant for item selection, some of the test contents are covered by the subject areas of science education in participating countries (Olsen, Lie, & Turmo, 2001).

The *Knowledge* domain of the first two PISA surveys (conducted in 2000 and in 2003) covers thirteen topics related to science disciplines and includes integrative concepts and knowledge components that are important for everyday life and needed for interpreting and explaining certain features of our environment. For example: *Chemical and physical changes*, *Forces and movement*, *Human biology*, *Atmospheric changes* etc. (B. Németh, 2008; OECD, 1999, p. 64; 2003, p. 136).

In the PISA assessment of 2006, where scientific literacy was in focus, the assessed content was based on a knowledge system related to science and nature and necessary for the understanding of nature. The ratio of the two major areas of the *Knowledge* dimension in the tests, i.e. knowledge of science and knowledge about science, was 3 to 2 (OECD PISA, 2006). The category of the knowledge of science is made up of the thematic units of the four major fields of science (Physical systems, Living systems, Earth and space systems, Technology systems). For example, the category of *Living systems* covers the topics of *Cells, Humans, Populations, Ecosystems and Biosphere*. The category of knowledge about science tests two concepts: scientific explanations and scientific enquiry. The latter is, for instance, divided into topics such as *Measurement*, *Data type*, *Characteristics of results*, etc.

The Assessment of Cognitive Dimension

Scientific literacy is defined by every literacy model – regardless of its approach, emphasis and formulation – as applicable knowledge. The notion of application is used widely and with a variety of interpretations. Sternberg (1985), for instance, lists application as the fourth step of the seven steps of creative reasoning, and interprets it as a process of rule generation through the extrapolation of old and new concepts. Passey (1999) juxtaposes application with abstraction and transfer.

In educational sciences, the concept of application is generally used as a synonym for operationalising and putting knowledge to use as a tool. The different interpretations usually link it to various activities related to task completion (counting, interpretation, depiction, linking, modification, supplementation, verification etc.; e.g., Anderson & Krathwohl, 2001; Mullis et al., 2005, pp. 41–77; Nagy, 1979). Huitt (2004) defines application as the use of data and principles in solving problems or tasks, and as selection and transfer. According to another approach, application is the selection and use of information (rules, methods and theories) in new and concrete contexts in an effort to complete tasks and solve problems.[8] According to the interpretation of József Nagy (1979), application is an operative (transforming) and cognitive activity.

In education theory, knowledge is considered to be applicable if it can be successfully used to deal with given real-world problems. In this framework, scientific literacy as applicable knowledge is characterised by answers to questions such as "How to know?", "What to be able to do?". The desired behaviour is organised into a hierarchical system based on various cognitive taxonomies. Application is considered to be an autonomous category in several taxonomies, marked by the labels "*apply*", "*applying*", or "*application*" (e.g., the First International Science Study of IEA – Commbers and Keevs, 1973; Mullis et al., 2009, p. 50; also Anderson & Krathwohl, 2001; Bloom, 1956; Madaus et al., 1973). In curriculum and assessment standards, cognitive activity is usually characterised by a revised and improved version of the Bloom taxonomy and with competency models.

Although Bloom's (1956) foundational system has received a lot of criticism, its revised version continues to be widely used in developing educational goals and evaluation criteria. The lower three levels (*knowledge*, *comprehension* and *application*) of Bloom's systematic and hierarchical system, which established the taxonomic approach in the field, still appear in current theoretical frameworks, albeit with some minor modifications in terminology (e.g., *knowledge/recall*; *comprehension/understanding*) or interpretation. The criticisms appearing in the literature mainly concern the interpretability and discriminability of higher-order reasoning processes, i.e. analysis, synthesis and evaluation, and the connections between them. The model of Anderson and Krathwohl (2001), for instance, inverts the order of evaluation and synthesis, which the authors call creating. For Madaus et al. (1973) analysis and synthesis, for Huitt (2004) synthesis and evaluation, and for Johnson and Fuller (2006) all three processes are treated as activities of the same level of difficulty. Johnson and Fuller (2006, p. 121) also create a new category at the top of hierarchy, which they call higher application.

The IEA studies rely on a system developed from the Bloom taxonomy. The cognitive domain of the First International Science Study (FISS)

8 Downloaded on: 9 July 2008.: http://www.lifescied.org/cgi/content/full/1/3/63

and the Second International Science Study (SISS), for instance, consisted of knowledge, understanding, application and higher-order reasoning processes (Báthory, 1979; Commbers & Keevs, 1973). The three cognitive categories of the 2003 and 2007 cycles of the IEA-TIMSS studies cover essentially the same processes, albeit using different terminology. Bloom's foundational concepts are reflected in the category titles *Factual knowledge/Knowing* and in the contents of the categories *Conceptual understanding/Applying* and *Reasoning and analysis/Reasoning,* the latter of which covers higher-order processes (Mullis et al., 2001, pp. 37–70; 2005, pp. 41–77). Most of the processes included in these three categories[9] can be found in the conceptual framework of every IEA-survey. *Application/Applying* is the mid-level category of the cognitive domain in the FISS, the SISS, the 2007 assessment and the data collection scheduled for 2011 of the TIMSS studies (Commbers & Keevs, 1973; Keeves, 1992a; Mullis et al., 2005, pp. 41–77; 2009, pp. 88–89).

The spread of the cognitive approach and the shift in the approach to literacy are indicated by the fact that in the 2003 and 2007 cycles of the TIMSS studies and also in the 2011, the proportion of items assessing factual knowledge (the comprehension of simple and complex information and the knowledge of facts) has decreased significantly (from 69-70% to 30%). New types of tasks appeared, such as drawing conclusions, generalisation, the justification of explanations, the validation and evaluation of solutions, and listing of examples (see B. Németh, 2008, Tables 5 and 6; Mullis et al., 2009, p. 50). The shift in the interpretation of knowledge also manifests itself in the appearance of categories such as scientific inquiry, the communication of scientific results, recognising scientific evidence, understanding the interactions between mathematics and technology, and formulating conclusions in the three most recent TIMSS studies (Mullis et al., 2001, p. 69; 2005, p. 76; 2009, pp. 88–89). These categories are interpreted in a similar way to their counterparts in the OECD PISA programs, but they have little weight in TIMSS (Olsen, 2005, p. 26).

9 *Factual knowledge/Knowing*: e.g., knowing and using facts, information, correlations, tools and processes, understanding correlations − *Conceptual understanding/Applying*: e.g., understanding correlations, recognizing correlations, phrasing explanations − *Reasoning and analysis/ Reasoning*: e.g., interpreting processes, analyzing and solving problems, implementing assessments, etc.

In the PISA program, the cognitive domain of the knowledge to be measured is made up of a system of competencies. In the first two cycles, where a full coverage of literacy was beyond reach because of the limited resources, the cognitive domain termed *Scientific process* touches selectively upon the processes of the application of scientific thinking and knowledge, without attempting to construct comprehensive levels. The domain lists activities such as *Interpreting scientific concepts, phenomena and evidence*; *Drawing or evaluating conclusions*; and *Understanding scientific investigations* (OECD, 1999, p. 62; 2003, p. 137). The 2006 cycle, where scientific literacy is in special focus, includes three major competency categories: (1) *Identifying scientific issues*, (2) *Explaining phenomena scientifically* and (3) *Using scientific evidence*.

The National Educational Standards (NBS), which rely on a so-called normative competence model and conform to the German approach to literacy, characterise target competencies and thinking processes based on four categories of competency: subject knowledge, the application of epistemological and methodological knowledge, communication and judgment (Schecker & Parchmann, 2007).

The structure of the Australian NAP-SL contains elements similar to other national standards, but it is rooted in different theoretical considerations, distinguishing three categories:

"Strand A: formulating or identifying investigable questions and hypotheses, planning investigations and collecting evidence;

Strand B: interpreting evidence and drawing conclusions from their own or others' data, critiquing the trustworthiness of evidence and claims made by others, and communicating findings;

Strand C: using science understandings for describing and explaining natural phenomena and for interpreting reports about phenomena". (MCEETYA, 2006, pp. 3–4)

These three categories cover the five components of scientific literacy specified in the PISA surveys: (1) recognising scientific questions and evidence, (2) formulating, evaluating and communicating conclusions and (3) demonstrating an understanding of concepts (MCEETYA, 2006; OECD, 1999).

Each of the three categories is broken down to six levels of difficulty, the theoretical background for which is provided by Biggs and Collis'

(1982) *Structure of Observed Learning Outcomes* (SOLO) taxonomy, a qualitative assessment model based on the cognitive development theory of Piaget (1929). Biggs and Collis (1982) started with the assumption that the development of concepts and competencies has natural, age-specific stages building upon one another. Qualitative and quantitative changes, an increase in the level of understanding, and changes in the complexity of structure are all reflected in the performance of the student. The model classifies the quality of answers in terms of complexity and abstraction into five levels analogous with the cognitive developmental stages[10] of Piaget (1929): pre-structural, unistructural, multistructural, relational and extended abstract levels (Biggs & Collis, 1982; Biggs & Tang, 2007).

Distinguishing between concrete and abstract manifestations of the middle three levels (simple, complex and inter-related) of the SOLO taxonomy, NAP–SL specifies six levels of development among students in grades 1 to 6. These are the following:

Level (1): *concrete unistructural*: concrete simple answers in a given situation;
Level (2): *concrete multistructural*: concrete complex answers in different unrelated situations;
Level (3): *concrete relational*: concrete inter-related answers, generalisation;
Level (4): *abstract unistructural*: the use of abstract conceptual systems in a given situation;
Level (5): *abstract multistructural*: the use of abstract conceptual systems in different unrelated situations;
Level (6): *abstract relational*: the use of abstract conceptual systems in generalisation. (MCEETYA, 2006, pp. 81–82)

The Context of Assessment

In this day and age, it is an ever growing economic and social requirement to possess knowledge, acquired at school and elsewhere, that can be successfully deployed in real-world situations. Empirical studies sug-

10 Sensorimotor, preoperational, concrete and formal

gest, however, that the traditional institutional science education reliant on the 'pure science' of the curriculum cannot equip more than a few students with the kind of knowledge that is useful in everyday life (Calabrese Barton & Yang, 2000; Rennie & Johnston, 2004; Roth & Désautels, 2004; Ryder, 2001). Most students obtain that knowledge through personal experiences in situations involving issues of science outside of the school environment (Aikenhead, 2006; Rennie, 2006). The frequently experienced difficulties with the everyday applicability of classroom knowledge mostly stem from the dissimilar nature of the situation of acquisition and the situation of application (Csapó, 2002). During the learning process, human reasoning and acting adapt to the environment (Clancey, 1992), and the knowledge component (knowledge, skill, ability) to be acquired and its context together form a memory trace during the course of information processing (Wisemann & Tulving, 1976). Wisemann and Tulving (1976) have found evidence that the activation of memory traces is influenced by the relationship between the stored information and the information accessible at the time of recall, i.e., the degree of similarity between the context of learning and the context of application (Tulving, 1979). That is, the activation of knowledge is easier in known/familiar situations corresponding to the situation of acquisition than in an unfamiliar context with no mental representation in memory. The situational, context-dependent nature of knowledge (Clancey, 1992) in some cases facilitates and in other cases inhibits its applicability in different problem situations (Schneider, Healy, Ericsson, & Bourne, 1995). Decontextualised classroom learning devoid of hands-on experiences (may) cause difficulties with the understanding of school knowledge and its application outside the classroom (Csapó, 2001). The standards of operational knowledge/literacy need to specify the context of application as well.

While the taxonomisation of the content and cognitive domains of the knowledge taught and expected to be acquired are rooted in traditions of decades (see e.g., Anderson & Krathwohl, 2001; Báthory, 2000; Beaton et al., 1996a; Commbers & Keeves, 1973; Kloppfer, 1971; Mullis et al., 2001; 2005; 2009), we rarely find a detailed description of contexts. Most standards of content and evaluation characterise the circumstances of knowledge application with attributes such as new, known/unknown, lifelike, realistic, authentic, real and everyday without naming explicit parameters. In Australia, for instance, assessments are carried out using authentic tasks set in lifelike contexts at every level of cognitive process and conceptual category in all three strands of literacy (MCEETYA, 2006, pp. 3–4), but no detailed context taxonomy has been developed so far. Anderson differentiates between applications in familiar versus unfamiliar situations, and calls the former *executing* and the latter *implementing* (Anderson, 2005, p. 9). Certain taxonomies break down the application level of cognitive behaviour to subcategories, specifying the application conditions and context of the given content. In the first handbook on evaluation, for example, Kloppfer (1971, pp. 561–641), identifies three subcategories of applying scientific knowledge and methods, the application of new problems in a few and distinct areas of science, and in areas beyond science and technology.

At an international level, the first attempt to assess the application of scientific knowledge by means of tasks representing everyday situations was made in 1995, in the first IEA-TIMSS study[11]. However, a systematic description of the circumstances of knowledge application, the development of a differentiated system of *contexts* and its integration into the parameters of measured knowledge first appeared at the turn of the millennium only, as part of the scientific literacy assessment of the OECD PISA program.

In line with the definition of literacy, the contexts used in the OECD PISA surveys can be classified into categories such as *Realistic,* or lifelike, and *Unknown,* or different from the learning situations at school, and represent real-world situations related to science and technology (OECD, 2006). The OECD PISA program uses a two-dimensional taxonomy. One aspect of constructing the task contexts is provided by pertinent topics in science and technology and current issues related to health, natural resources, the environment and the dangers and limits of science and technology. The second aspect of constructing the task contexts is given by situations representing problems related to personal (self, family, peer groups), social (the community), or world-wide issues[12] (OECD,

11 In later IEA-TIMSS studies, the measurement of scientific knowledge is again dominated by scientific terminology, and common situations as task contexts are no longer typical.

12 In the 2000 and 2003 surveys, questions on the history of science and technology were also included.

2006, p. 27). PISA 2006 assesses scientific competencies in contexts that play a real role in maintaining and improving the living standards of individuals and of the community. When selecting the task contexts, a further consideration was that the task situations should be familiar, interesting and important for the students of all participating countries (OECD, 2006, pp. 26–28).

Summary

The literature in education theory offers a barely manageable diversity of approaches to literacy. The notion of scientific/science literacy representing the basic goals, principles and tasks of science education has no commonly accepted interpretation (Bybee, 1997b; DeBoer, 2000; Laugksch, 2000; Roberts, 2007). The current frameworks for the content of science education and its assessment are individual systems constructed with the implicit (e.g., the IEA studies) or explicit (e.g., the Australian NAP-SL, or the German NBS) use of theoretical models. These theoretical models describe scientific knowledge/literacy in terms of the expected cognitive and affective behaviour of educated people. Some of the models characterise the quality of literacy with reference to competences (e.g., Gräber, 2000), and to the increasingly complex processes of the literacy manifestations of the various developmental levels evolving through the organisation of thinking (e.g., Bybee, 1997a; Shamos, 1995),

According to comprehensive literature reviews (see e.g., Aikenhead, 2007; Jenkins, 1994; Laugksch; 2000; Pella, O'Hearn & Gale, 1966; Roberts, 2007) the general expectations of the various approaches differing in their perspectives, emphasis and structures are similar and construct their models from a shared set of elements and with essentially the same considerations in mind. One point of agreement is, for instance, that the scientific knowledge taught and expected to be acquired must have both individual and social relevance. Also, there is a broad consensus that scientific literacy is a complex, multidimensional system of knowledge (Roberts, 2007) that comprises

- the knowledge of nature, familiarity with, the understanding and the application of the major concepts, principles and methods of science;
- recognition of the values, nature, goals and limits of science;

– a structured system of thinking processes, and the competencies needed for application;
– scientific ways of thinking;
– scientific interests and attitudes (Hurd, 2003; Jenkins, 1994).

The curriculum and evaluation standards used in practice share the feature that the metaphorical use of the concept of *scientific/science literacy,* and the generalised definition of literacy are supplemented by less universal descriptions (Holbrook & Rannikmae, 2009). The detailed goal specifications define the knowledge expected to be acquired and intended to be assessed at its different levels of development and organisation in terms of the three components determining its applicability: content 'What should be known?', thinking 'How should it be known?' and context 'Where, in what context should it be known?'. These three parameters provide the basis for the theoretical frameworks even if they are structured according to varied principles and formulated using different terminologies.

In science standards, context usually refers to science-related situations outside of the classroom where prespecified knowledge (content) has relevance. Context tends to be a broad category characterised by adjectives such as unified, everyday, real, and lifelike. A differentiated description of the context of knowledge application and its multidimensional organisation (issues and problems in personal, social and global contexts) only appear in the OECD-PISA program (OECD, 2006).

In the theoretical frameworks of science education and the assessment of knowledge/literacy, the cognitive processes expected to be acquired and intended to be measured are structured along different cognitive taxonomies and competencies. There are behavioural patterns that appear in several frameworks. Processes shared by most of the standards, regardless of the diversity of their theoretical backgrounds and their terminologies, include understanding, application, familiarity with and use of the methods of science, the description and explanation of natural phenomena, scientific communication, the drawing of conclusions, etc.

The various approaches to literacy mainly differ in their views on content. The method of structuring knowledge and the choice of major categories depend on the interpretation of the relationships between the different fields of science (disciplinary versus integrated approach) and on the evaluation of the role of science in education. The choice between a disciplinary, interdisciplinary or multidisciplinary approach to science is strongly influenced by national characteristics, cultural traditions, educational traditions and current goals. With respect to the interpretation of the interactions between the different fields of science and their relationship to other disciplines there are two opposite poles among the curriculum and evaluation standards (Roberts' 'Visions', Roberts, 2007). One pole is represented by approaches focusing on traditionally interpreted science disciplines (e.g., the German NBS/Schecker & Parchmann, 2006) while the other pole is represented by views integrating natural and social sciences (e.g., Taiwan: Chiu, 2007; Israel: Mamlok-Naaman, 2007). The majority of approaches integrate various science disciplines in different ways and at different levels.

To our knowledge, no explicit model of scientific literacy is offered in the Hungarian research literature or in documents of education policy. The picture emerging from the 2007 version of the National Curriculum, the various curriculum frameworks and the school-leaving examination standards suggest that in Hungary, science education is largely discipline-oriented in terms of its approach, methods and structure. In grades 7 to 12, teaching is organised along the traditional academic subjects of Biology, Physics, Geography and Chemistry representing the traditional fields of science. Although the school subject '*Environmental Studies*' taught in grades 1 to 4 and the subject '*Nature Studies*' taught in grades 1 to 6 cover the four major disciplines, the integration is only a matter of form, as the different fields of science are clearly separated in the subject syllabi. The dependence on individual disciplines is also reflected in the characteristics of the knowledge taught.

The theory-oriented education that follows the logic of the different fields of science is efficient in a narrow section of the student population, as has been demonstrated by the performance of Hungarian scientists and engineers and the successes achieved at student Olympics. There are several signs indicating that the high-quality disciplinary and academic knowledge that can be acquired in Hungarian schools has rather weak personal and social relevance and fails to equip the majority of students, those not intending to pursue a scientific career, with the kind of knowledge they need to cope in the real world (e.g., B. Németh, 2003; Martin et al., 2008). According to the PISA studies, in Hungary students' applicable knowledge of science is at an average level in an international context and a growing proportion of our students perform poorly (e.g., B. Németh, 2003; Martin et al., 2008; OECD, 2010).

To move on, we need to reconsider our own approach to literacy taking international experiences into account, and seeking ways of incorporating them into our educational traditions. In order to develop a model of literacy offering knowledge that satisfies the expectations of our age and can be deployed by ordinary citizens in their everyday lives, several factors need to be considered. The model of literacy specifying the goals and guiding principles of science education should offer knowledge of social and personal relevance accessible to everyone; it should adopt the latest widely accepted results of research in psychology and education sciences, encourage an interest in science and conform to modern international trends, while at the same time building on the positive traditions of Hungarian education as the international experiences are incorporated.

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